TECHNICAL GUIDANCE FOR DESIGN OF THE SUBSURFACE DRAINAGE FOR MILITARY PAVEMENTS

1. Introduction. Except in frost areas, the current design criteria for military pavements, as given in Th 5-822-S/AFM 88-7, Chap. 3; TM 5-822-2/ AFM 88-7, Chap. 5; TM 5-825-3/AFM 88-6, Chap 3; and Th 5-825-2/AFM 88-6, Chap. 2, are based on the assumption that the base and subbase layers will be adequately drained, i.e., the criteria do not consider damage because of free water at layer interfaces nor for a loss of material strength caused by pore pressures induced by traffic. To ensure adequate subsurface drainage, major changes to the criteria for design of subsurface facilities (TM 5-820-2/ AFM 88-5, Chap. 2 and TM 5-818-2/AFM 88-6, Chap. 4) are being implemented. The changes involve modifying the gradation for base materials, requiring a drainage layer for most pavements, adding procedures for design of the drainage layers, limiting the time for drainage of the base, and supersedes the guidance in TM 5-818-2/AFM 88-6 for a free draining base in frost areas.

2. Definitions.

a. Drainage Layer. A drainage layer is a layer in the pavement structure that is specifically designed to allow horizontal drainage of water from the pavement structure. The layer is also considered to be a structural component of the pavement and will serve as part of the base or subbase. The drainage layer will consist of either a rapid draining material or an open graded material and will be designed by criteria provided in this Engineer Technical Letter(ETL).

b. Separation Layer. A separation layer is a layer provided directly beneath the drainage layer to prevent fines from infiltrating or pumping into the drainage layer and to provide a working platform for construction and compaction of the drainage layer. Generally, a minimum of 4 in. of dense-graded aggregate material is used; however, a filter fabric can be used. The material for the granular separation layer should meet the requirements for a 50 CBR subbase as given in Th 5-822-5/AFM 88-7, Chap. 3 and Th 5-825-2/ AFM 88-6, Chap. 2. The requirements for filter fabric are given in TM 5-820-2/ AFM 88-5, Chap. 2.

c. Rapid Draining Material (RDM). A rapid draining material is a material having a sufficiently high permeability (1,000 to 5,000 ft/day) to serve as a drainage layer and will also have the stability to support construction equipment and the structural strength to serve as a base and/or a subbase. Gradation limits for the RDM are given in Table 1, and the design properties are given in Table 2. To ensure adequate stability and strength, the uniformity coefficient (C~) of the RDM should be greater than 3.5.

d. Open Graded Material (0GM). An open graded material is a material having a very high permeability (greater than 5,000 ft/day) which may be used for a drainage layer. Such a material will normally require stabilization for construction stability or for structural strength to serve as a base in a flexible pavement. Gradation limits for the OGM are given in Table 1, and the design properties are given in Table 2.

Table 1

Gradations of Materials for Drainage Layers and Choke Stone

Sieve Designation	Drainage Layer Material: Rapid Draining Material	Drainage Layer Material: Open Graded Material	Choke Stone
1-1/2 in.	100	100	100
1 in.	70-100	95-100	100
3/4 in.	55-100	--	100
1/2 in.	40-80	25-80	100
3/8 in.	30-65	--	80-100
No. 4	10-50	0-10	10-100
No. 8	0-25	0-5	5-40
No. 16	0-5	--	0-10

Table 2

Properties of Materials for Drainage Layers

Property	Rapid Draining Material	Open Graded Material
Permeability ft/day	1;000-5,000	>5,000
Effective Porosity	0.25	0.32
Percent Fractured	90% for 80 CBR	90% for 80 CBR
Faces (COE method)	75% for 50 CBR	75% for 50 CBR
C_v	>3.5	--
LA Abrasion	<40	<40

Note: C_v is the uniformity coefficient = D_{60}/D_{10}.

e. Choke Stone. A choke stone is a small size stone used to stabilize the surface of an OGM. The choke stone should be a hard, durable, crushed aggregate having 90 percent fractured faces. The ratio of D_{15} of the coarse aggregate to the D_{15} of the choke stone must be less than 5, and the ratio of the D_{50} of the coarse aggregate to D_{50} of the choke stone must be greater than 2. The gradation range for acceptable choke stone is given in Table 1. Meeting the requirements of a choke stone would be either the ASTM No. 8 or ASSHO No. 9 stone.

f. Coefficient of Permeability. The coefficient of permeability is a measure of the rate at which water passes through a unit area of material in a given amount of time under a unit hydraulic gradient.

g. Effective Porosity. The effective porosity is defined as the ratio of the volume of voids that will drain under the influence of gravity to the total volume of a unit of aggregate. The difference between the porosity and the effective porosity is the amount of water that will be held by the aggregate. For materials such as the RDM and 0CM, the water held by the aggregate will be small; thus, the difference between the porosity and effective porosity will be small (less than 10 percent). The effective porosity may be estimated by computing the porosity from the unit dry weight of the aggregate and the specific gravity of the solids which then should be reduced by 5 percent to allow for water retention on the aggregate.

h. Stabilization. Unless experience indicates otherwise, stabilization of OGM is required for stability and strength, and for preventing degradation of the aggregate in handling and compaction. Stabilization may be accomplished mechanically by use of a choke stone or by the use of a binder such as asphalt or cement. The choke stone will be used only with the OGH and will be referred to as a choked OGM. The asphalt or cement may be used with the OGM and will be referred to as an asphalt or cement stabilized OGM. Stabilization of the CGM is accomplished by using only enough asphalt or cement paste required to coat the aggregate. Care should be taken so that the voids are not filled by excess stabilizer. The stabilization material predominantly used is asphalt cement (AC-20) at 2 to 2-1/2 percent (by weight) for the OGH. Higher asphalt cement percentages are required when a less open graded material is used. For example, New Jersey’s asphalt cement stabilized permeable base gradation requires 3 percent asphalt cement to coat the aggregates. For additional asphalt stabilized permeable base stability, a stiffer asphalt cement, such as an AC-40, should be used. Portland cement at 1-1/2 to 3 bags/cu yd has also been used. As with asphalt cement stabilized permeable base, the amount of portland cement per cubic yard will depend on the voids and surface area of the aggregate in the permeable material. For example, California uses not less than 282 lb of portland cement per cubic yard with a water-cement ratio of 0.37. The permeability of this material is approximately 4,000 ft/day. Whereas, Wisconsin with a more open material (permeability approximately 10,000 ft/day) has found that 200 lb of portland cement per cubic yard and a water-cement ratio of 0.37 provide adequate strength, durability, and stability.

i. Degree of Drainage. The degree of drainage is the ratio of water that has drained from a material to total amount of water that the material is capable of holding.

3. Drainage Criteria.

a. Concepts. For pavements in nonfrost areas and having a subgrade with a permeability greater than 20 ft/day, one can assume that the vertical drainage will be sufficient such that no drainage layer is required. Also, flexible pavements in nonfrost areas and having a total thickness of 8 in. or less are not required to have a drainage layer. For pavements requiring drainage layers, the design of the drainage layer shall be based on the premise that the capacity of the drainage layer should be greater than the volume of water entering the pavement, and that the drainage layer, if saturated, should reach a degree of drainage of 0.85 within 1 day after the inflow of water stops. The degree of drainage for the drainage layer is defined as the volume of water that has drained from the layer over a specified time period divided by the total volume of water in the layer that can be drained by gravity.

b. Design Water Inflow. The subsurface drainage of the pavement is to be designed to handle water infiltration through the pavement from a design storm index for a design storm of 1 hr duration at an expected return frequency of 2 years. For the continental United States, this can be determined from Figure 1 (taken from Th 5-820-l/AFM 88-5, Chap. 1). Guidance for determining the design storm for other parts of the world is also given in Th 5-820-1/ AFM 88-5, Chap. 1. The inflow is determined by multiplying the design rainfall index CR in inches per hour) times an infiltration coefficient F. This coefficient will vary over the life of the pavement depending on the type of pavement, surface drainage, pavement maintenance, and structural condition of the pavement. Since the determination of a precise value of the infiltration for a particular pavement is very difficult, a value of 0.5 may be assumed for design. The value of the coefficient may be changed based on local experience and anticipated inflow rates for a particular pavement. The rate of water inflow (q in cubic feet per foot width of drainage path per hour) is then computed by the equation

$$q - L \times F \times (R/12) \qquad \text{(eq 1)}$$

where

L = length of the drainage path in feet
F = infiltration coefficient
R = design rainfall index in inches per hour

It should be noted that the drainage layer design is based only on the infiltration of water from the surface. Normally, other sources would provide

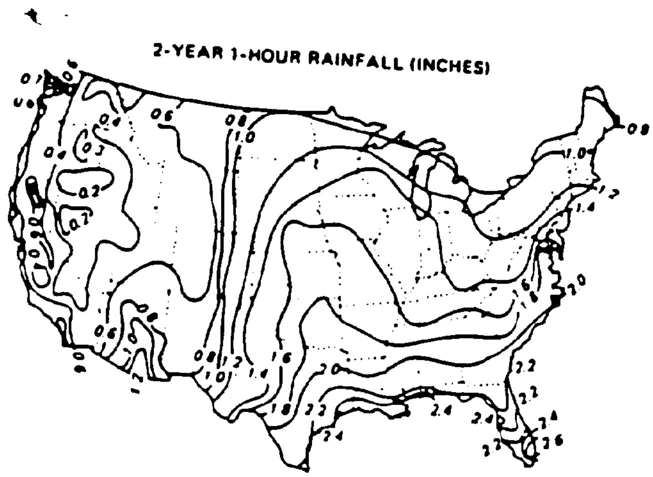


Figure 1. Design Storm Index, 1-hr Rainfall Intensity-Frequency Data for Continental United States Excluding Alaska (Chart reproduced from US Weather Bureau, Technical Paper No. 40, Rainfall Frequency Atlas of The United States, Washington, DC, May 1961.)

water to the drainage layer but such water would be minor and would not be a consideration in the design of the drainage layer. Should ground water be present in any substantial quantities, special provisions should be made to intercept and drain the water before it reaches the drainage layer. The drainage layer is expected to aid in draining of water in the subbase and subgrade caused by frost action, but this volume of water will not be considered in computing the design water inflow.

c. Length and Slope of Drainage Path. The length of drainage path is measured along the slope of the drainage layer from the crest of the slope to where the water will exit the drainage layer. In simple terms, the length of the drainage path is the maximum distance water will travel in the drainage layer. The length of drainage path (L) in feet may be computed by the equation

$$L = \frac{X\sqrt{i_t^2 + i_e^2}}{i_t} \qquad \text{(eq 2)}$$

where

X = the length in feet of the transverse slope of the drainage layer

i_t = the transverse slope of the draining layer
$i_.$ = the longitudinal slope of the drainage layer

The slope (i) of the drainage path may be computed by the equation

$$i = \sqrt{i_t^2 + i_\bullet^2} \qquad \text{(eq 3)}$$

d. Capacity of Drainage Layer. The capacity of the drainage layer (Q in cubic feet per foot width of pavement) is computed based on the effective porosity (n~) and the volume of water draining from the drainage layer during the 1 hr of water inflow. Since the criterion is for a degree of drainage of 0.85 within 24 hr, it is to be assumed that only 85 percent of the voids will be available for storage of water. Thus, the capacity of the drainage layer may be computed by the equation

$$Q = (0.85)\ (n_.)\ (H)\ (L) + (k/24)\ (t)\ (i)\ (H)/2 \qquad \text{(eq 4)}$$

where

Q = capacity of the drainage layer in cubic feet/feet
$n_.$ = effective porosity
H = thickness of the drainage layer in feet
L = length of the drainage path in feet
k = permeability of the drainage layer. in feet/day
t = 1 hr (length of design storm)
i = slope of the drainage path in feet/foot

e. Thickness of Drainage Layer. By setting Q - q and substituting equations 1 and 4 for q and Q, the minimum thickness in feet of the drainage layer required to provide the storage capacity for a 1 hour design storm is determined from the equation

$$H = 4\ F\ R\ L/[40.8\ n_\bullet\ L + ki) \qquad \text{(eq 5)}$$

If the term (ki) is small compared to the term ($40.8n_\bullet L$) which would probably be the case for long drainage paths (> 20 ft), then the required thickness of the drainage layer can be estimated by deleting the term (ki) from equation 5 or

$$H = (F\ R)/(l0.2\ n_{\bullet}) \qquad \text{(eq 6)}$$

The value of H obtained from equation 6 will always be somewhat greater than the value of H determined from equation 5. In no case should the thickness of the drainage layer be less than 4 in.

f. <u>Time for Drainage.</u> The time for drainage of the drainage layer is a function of effective porosity, length of the drainage path, thickness of the drainage layer, slope of the drainage path, and permeability of the drainage layer. This function has been solved in terms of time factor TF and a parameter m. The time factor is obtained from Figure 2 as a function of the parameter s which is determined by the equation

$$s = Li/(H) \qquad \text{(eq 7)}$$

After determining the time factor TF from Figure 2, the time required to obtain a degree of drainage of 0.85 is computed from

$$T_{85} = (TF)(m) \qquad \text{(eq 8)}$$

where

T_{85} = time in days required to obtain a degree of drainage of 0.85
m = a parameter defined as

$$(n_{\bullet}\ L^2)/(k\ H) \qquad \text{(eq 9)}$$

g. <u>Design Example.</u> Assume the following design parameters are appropriate for a large parking lot.

The design rainfall (R) = 2.0 in.

The effective porosity ($n_{\bullet}$) = 0.2

The length of the drainage path (L) = 150 ft

The permeability of the drainage material (k) = 2,000 ft/day

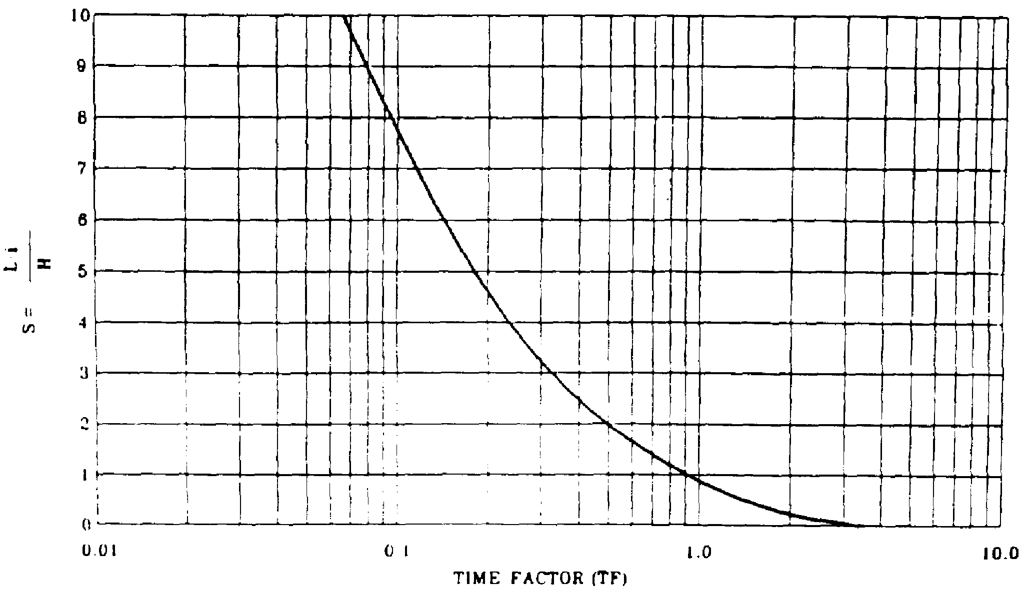


Figure 2. Time Factor for 85 Percent Drainage

The slope of the drainage path (i) = 0.01

The infiltration coefficient (F) = 0.5

First the thickness, H, of the drainage layer required to provide the necessary storage capacity is computed by substituting into equation 5 as follows

$$H = [4(0.5)(2.0)(150)]/[40.8(0.2)(150) + (0.01)(2,000))$$

$$H = 0.48 \text{ ft. or } 5.8 \text{ in.}$$

Rounding the computed thickness up to the next full inch gives a design thickness of 6 in. Equation 6 could have been used to estimate the thickness as follows

$$H = F\,R/10.2\,n_e = [(0.5)(2)]/[(10.2)(0.2)] = 0.49 \text{ ft}$$

Again the thickness would round up to 6 in. The next step would be to use Figure 2 to determine the time to obtain a degree of drainage of 0.85. Using equation 7 the value of s is computed to be 3.0 and from equation 9 the value of m is computed to be 4.5. From Figure 2 the time factor, TF, is found to be 0.32. The time to obtain a degree of drainage of 0.85 is computed from equation 8.

$$T_{85} = (TF)(m) = (0.32)(4.5) = 1.44 \text{ days}$$

Since 1.44 days is considerably greater than the 1 day allowed by the criteria, the design must be modified to obtain a shorter time for drainage. The parameter that can be changed will depend on the particular design situation but for this example assume the design can be modified to obtain a drainage path of 100 ft. The thickness required for storage is found from equation 5 to be 6 in. The s parameter for entering Figure 2 is now 2.0 which gives a time factor, TF, of 0.5. The m parameter is computed from equation 8 to be 2.0. Equation 7 is again used to compute T_{85}.

$$T_{85} = (TF)(m) = (0.5)\ (2.0) = 1 \text{ day}$$

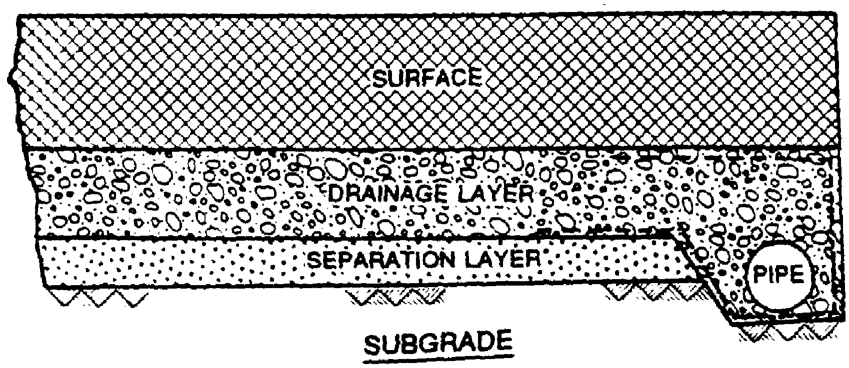
The 1 day required for drainage meets the criteria; thus, the design would call for a 6-in. drainage layer with a 100-ft drainage path.

4. Placement.

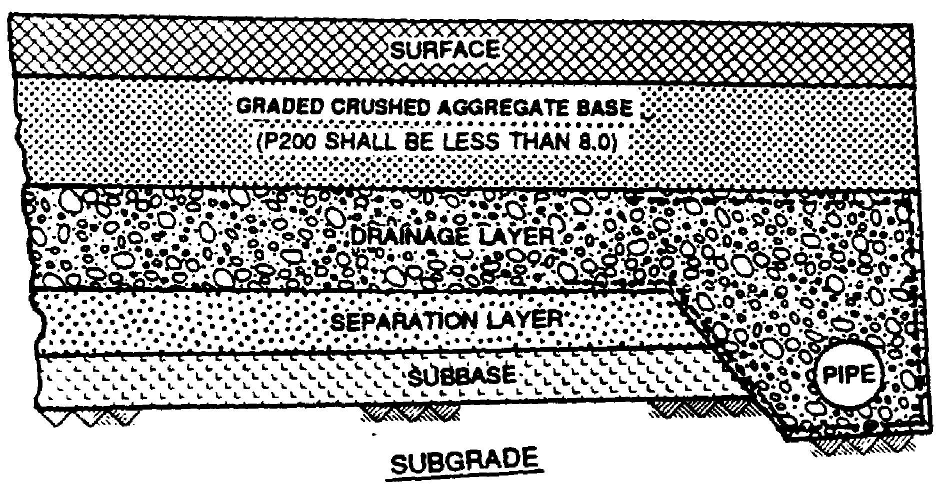
a. Rigid Pavements. In the case of rigid pavements the drainage layer, if required, shall be placed as shown in Figure 3a directly beneath the concrete slab. In the structural design of the concrete slab the drainage layer along with any granular separation layer shall be considered a base layer, and structural benefit may be realized from the layers.

b. Flexible Pavements. In the case of flexible pavements the drainage layer should be placed either directly beneath the surface layer as shown in Figure 3a or beneath a graded crushed aggregate base course as shown in Figure 3b. If the thickness of granular subbase is equal to or greater than the thickness of the drainage layer plus the thickness of the separation layer. the drainage layer is placed beneath the graded crushed aggregate base (Figure 3b). Where the total thickness pavement structure is less than 12 in., the drainage layer may be placed directly beneath the surface layer (Figure 3a) and the drainage layer would serve as the base. When a graded crushed aggregate base is used above the drainage layer, care must be taken to limit the material passing the No. 200 sieve in the graded crushed aggregate base to 8 percent or less. These precautions are necessary to provide adequate drainage and to ensure that an excess of fines will not be available to wash into the drainage layer. Should a graded aggregate base not be available, then it is suggested that an asphalt stabilized base be used above the drainage layer. In areas where frost will penetrate the base, the base must also meet the criteria in Th 5-8l8-2/AFM 88-6, Chap. 4 for a nonfrost susceptible material.

5. Separation layer. The drainage layer must be protected from contamination of fines from the underlying layers by a separation layer to be placed directly beneath the drainage layer. In most cases the separation layer should be a graded aggregate material meeting the requirements of a 50 CBR subbase. The minimum thickness for the separation layer is 4 in. A granular separation layer provides a firm foundation for compaction of the drainage layer and adds strength to the pavement structure. For design situations where a firm foundation already exists and the thickness of the separation layer is not needed in the structure for protection of the subgrade, a filter



3a. Placed Under Surface



3b. Placed Under Base

Figure 3. Drainage Layer Placement

fabric may be substituted for the granular separation layer. The fabric must meet the requirements specified in Th 5-820-2/AFM 88-5, Chap. 2.

6. Material Properties.

a. Strength and Durability. The material for a drainage layer should be a hard, durable crushed aggregate. Crushed aggregate meeting the gradation requirements of the RDM will provide sufficient stability for the drainage layer on which construction equipment such as dump trucks, transit trucks, and tracked pavers can operate.

b. Material Permeability. The permeability of the drainage layer is primarily a function of the material gradation and density. For a given gradation, it is important for strength considerations to obtain the maximum possible density during compaction without crushing the aggregate. Thus, the permeability is controlled by controlling the gradation. Table 2 provides estimates for the permeability of RDM and 0CM that are applicable to the gradation of the in-place material. There should be very few design situations requiring drainage materials having permeabilities greater than 5,000 ft/day; thus, the 0CM will almost always meet the permeability requirements. For RDM, a permeability of 2,000 ft/day may be used for design. If the required permeability is between 2000-5000 ft/day the RDM may be used provided the RDM is restructured to the coarse side of the gradation band. This value or laboratory determined permeability value may be used as estimates of the in-place permeabilities until local experience with construction of drainage layers can establish the in-place permeabilities being obtained.

7. Construction.

a. Experience. Without properly trained personnel, construction of the drainage layer can cause problems. Experience with highly permeable bases (drainage layers) both by the Corps of Engineers and various State Departments of Transportation indicates that pavements containing such layers can be constructed without undue difficulties provided certain guidelines are followed. These guidelines are discussed below.

b. Placement. The material for the drainage layer must be placed in a manner to prevent segregation and to obtain a layer of uniform thickness. The materials for the drainage layer will require extra care in stockpiling and handling. Placement of the RDK and OGM is best accomplished using an asphalt concrete paver. To ensure good compaction, the maximum lift thickness should be no greater than 6 in. If choke stone is used to stabilize the surface of 0CM, the choke stone is placed after compaction of the final lift of OCM. The choke stone is spread in a thin layer no thicker than ½ in. using a spreader box or paver. The choke stone is worked into the surface of the 0CM by the use of a vibrator roller and by wetting. The choke stone remaining on the surface should not migrate into the OCM by the action of water or traffic.

c. Proof Rolling. For Army Class IV and Air Force heavy, modified heavy, and medium load flexible airfield pavements. proof rolling as per TM 5-825-2/ AFM 88-6 Chap. 2, is required on the graded crushed aggregate base even when used over a drainage layer. Proof rolling the separation layer prior to placement of the drainage layer for other pavements is recommended. For other Air Force flexible pavements and Army Class III flexible pavements, it is recommended that the proof rolling be accomplished using a rubber-tired roller with each tire loaded to 20,000 lb or more and inflated to at least 90 lb/ sq in. A minimum of six coverages should be applied where a coverage is the application of one tire print over each point in the surface of the designated area. For rigid pavements and flexible pavements for roads, streets, parking lots and Class I and II Army airfields, proof rolling of the separation layer may be accomplished using the rubber-tired roller described above or by using a truck having tandem axles with either dual tires or super single tires. The truck should be loaded to provide 20,000 lb per axle. During proof rolling, action of the separation layer must be monitored for any sign of excessive movement or pumping that would indicate soft spots in the separation layer or the subgrade. Since the successful placement of the drainage layer depends on the stability of the separation layer, all weak spots must be removed and replaced with stable material. All replaced material must also be proof rolled as specified above.

d. Compaction. Compaction is a key element in the successful construction of the drainage layer. Compaction control normally used in pavement construction is not appropriate for materials such as the RDK and OGM. It is therefore, necessary to specify compaction techniques and level of effort instead of the properties of the end product. It will be important to place the drainage material in relatively thin lifts (6 in. or less) and to have a good firm foundation beneath the drainage material. The recommended method of determining the required compaction effort is to construct a test section and closely monitor the aggregate during compaction to determine when crushing of the aggregate appears excessive. Experience has indicated that sufficient compaction can be obtained by six passes or less of a 10-ton vibrator roller. Material not being stabilized with asphalt or cement should be kept moist during compaction. Asphalt stabilized materials for the drainage layer must be compacted at a somewhat lower temperature than a dense-graded asphalt material. In most cases it will be necessary to allow an asphalt stabilized material to cool to less than 200~ F before compaction. After compaction, the drainage layer should be protected from contamination by fines from construction traffic or from flow of surface water. It is recommended that the surface layer be placed as soon as possible after placement of the drainage layer. Precautions must also be taken to protect the drainage layer from disturbance by construction equipment. Only tracked asphalt pavers should be allowed for paving over any RDM or OGM that has not been stabilized. Drivers should avoid rapid acceleration, hard braking, or sharp turning on the completed drainage layer.

e. In-place Permeability. The permeability of an RDM can easily be reduced to an unacceptable level by over compaction or contamination with fines. The in-place RDM should easily accept the inflow of water without ponding or flowing across the surface. In-place permeability tests for materials as open as the RDM are difficult to run but may be conducted to get estimates of the in-place permeability. laboratory permeability tests may be conducted, but care must be taken to ensure that the laboratory samples are representative of the in-place material. In laboratory tests the permeability is normally measured in the direction of compaction, whereas, in the drainage layer the water flow is perpendicular to the direction of compaction. If such is the case, the field permeability may be an order of magnitude higher than the laboratory permeability.

8. Collector Drains.

a. Design Flow. It is absolutely essential that all pavements having drainage layers be provided with collector systems as specified in TM 5-820-2/ AFM 68-S, Chap. 2, such that positive relief of water from the pavement will be provided. The collector system should have the capacity to handle the water from the drainage layer plus water from other sources. The volume of water entering the collector system from the drainage layer is computed assuming the drainage layer is flowing full. Thus, the volume of water (Qo) in cubic feet per day per foot of length of collector (assuming the drainage layer is only on one side of the collector) would be

$$Qo = H \times I \times k \qquad \text{(eq 10)}$$

where

H = thickness of the drainage layer in feet
I = slope of the drainage layer in feet/feet
k = permeability of the material in the drainage layer in feet/day

If the collector system has water entering from both sides, the volume of water entering the collector would be double that given by equation 10.

b. Collector Pipe. The collector pipe may be perforated flexible, ABS, corrugated polyethylene or smooth rigid polyvinyl chloride pipe. The minimum size pipe that is to be used for a collector pipe is 6 in. and the mid height of the pipe is to be located a minimum of 12 in. below the separation layer. The backfill material around the collection pipe is to an 0CM (or RDM provided the drain layer is RDM) and is to be protected from infiltration of fines by a filter fabric. In areas where frost is predicted to penetrate to the depth of the collector trench and differential heave would cause problems, the sides of the trench above the depth of frost penetration shall be sloped not steeper than 1 vertical on 10 horizontal. Typical details for

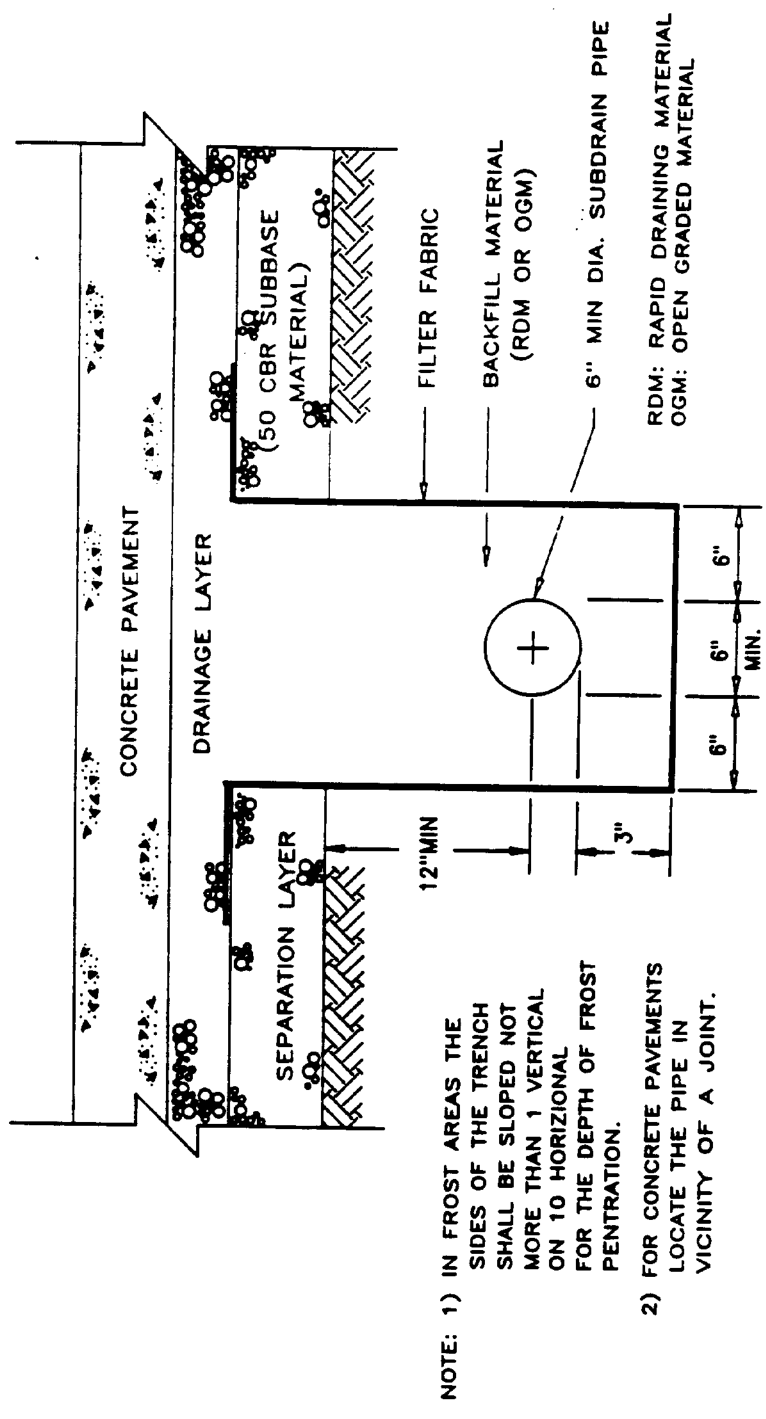


Figure 4. Typical Concrete Pavement Interior Subdrain Detail

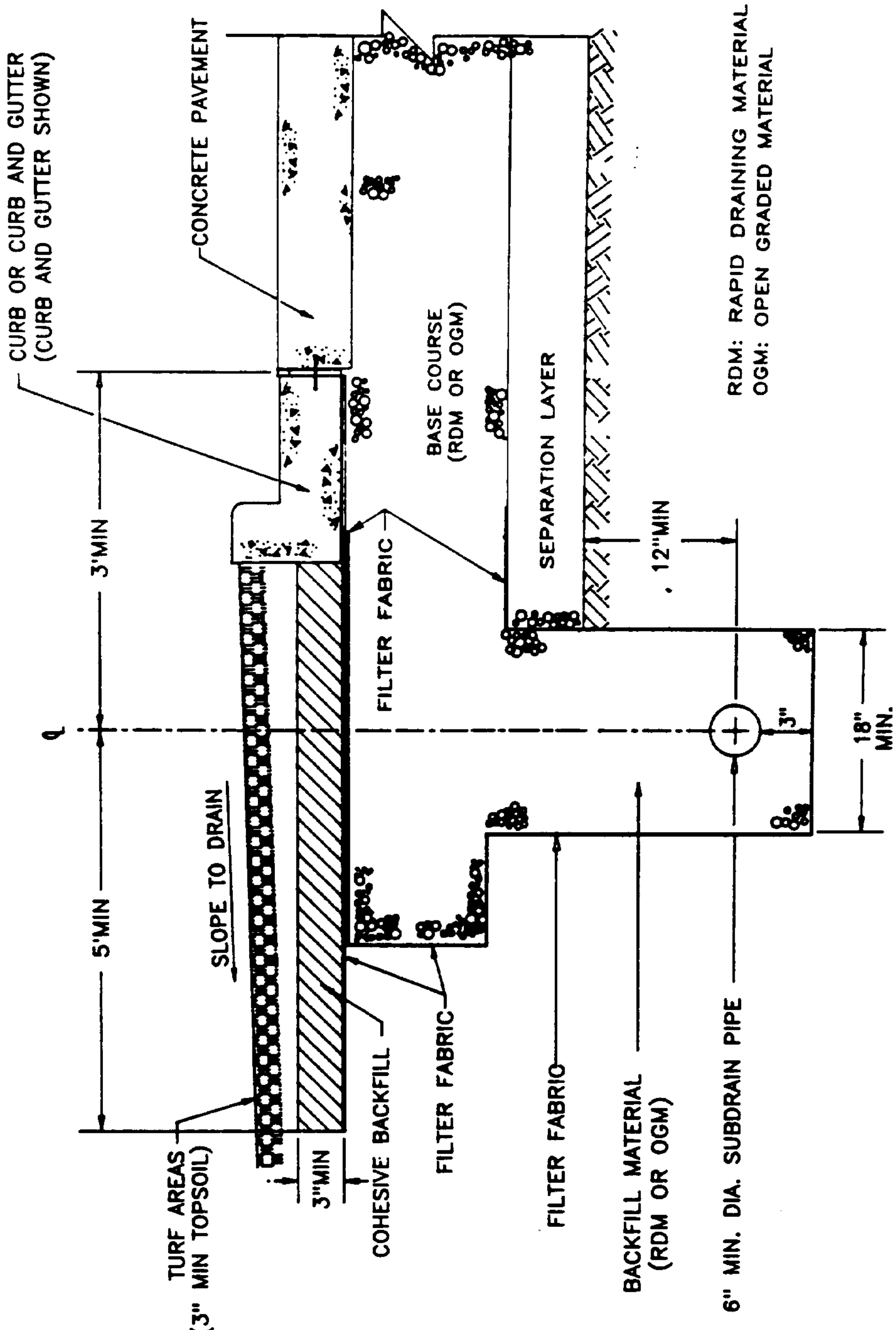


Figure 5. Pavement Edge Subdrain for Concrete Pavements

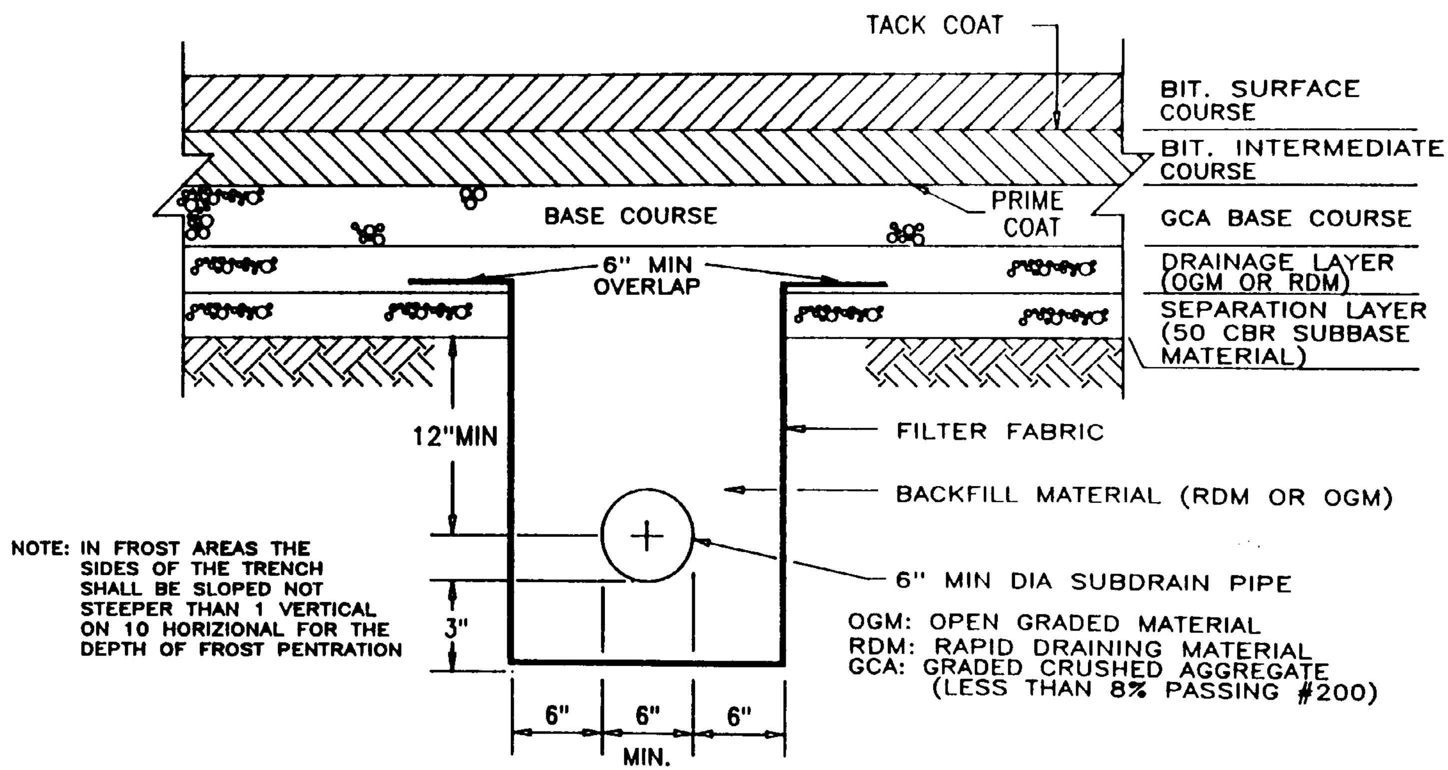


Figure 6. Typical Bituminous Pavement Interior Subdrain Detail

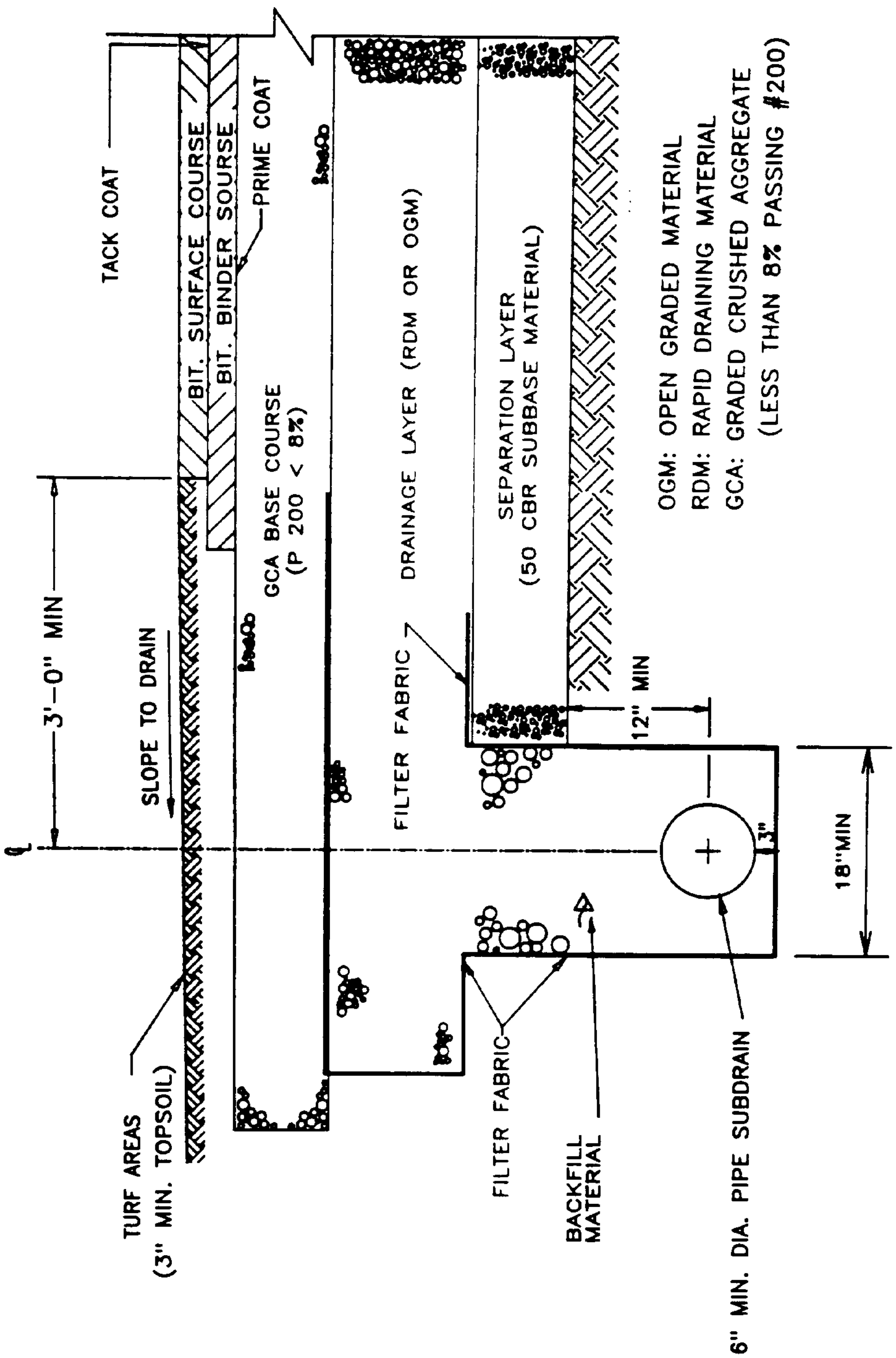


Figure 7. Typical Pavement Edge Subdrain for Bituminous Pavements

installation of the collector system are given in Figures 4, 5, 6, and 7. Note that the details given in these figures are only typical details and should not be taken as being mandatory. Normally, the collector pipes are to be located along the edge of the pavements but for parking lots, airfield aprons, or other pavements which would have long drainage distances the collector pipes may be located under the pavement.

c. lateral Outlet Pipe. In most installations outlet pipes to an open ditch or storm drains are required for the proper functioning of the collection system. In areas of frost, special consideration must be given to prevention of the freezing of the outlets. It is recommended that a metal or rigid solid-walled pipe be used for the lateral outlet pipe to ensure the proper grade and to prevent crushing by mowing operations. To ensure water does not back into the collector system. a 3 percent slope of the pipe to the ditch and a 6-in. freeboard for the pipe invert at the outlet over the 2-year design flow in the ditch as shown in Figure 8 are recommended.

d. Outlet Structure. Where the collection system outlets on a slope as shown in Figure 8, outlet structures are recommended to provide protection of the outlet pipe, prevent slope erosion, facilitate the location of outlet pipe for maintenance, and provide rodent protection. Headwalls of the outlet structure should be placed flush with the slope so that mowing operations are not impaired. Positive grades should be provided so that the headwall apron will drain. Reference markers for the outlet structure are recommended to facilitate locating structure for maintenance or observation.

e. Manholes and Clean-outs. The provisions of TM 5-820-2/AFM 88-5, Chap. 2 should be followed as to the design and installation of manholes and clean-outs.

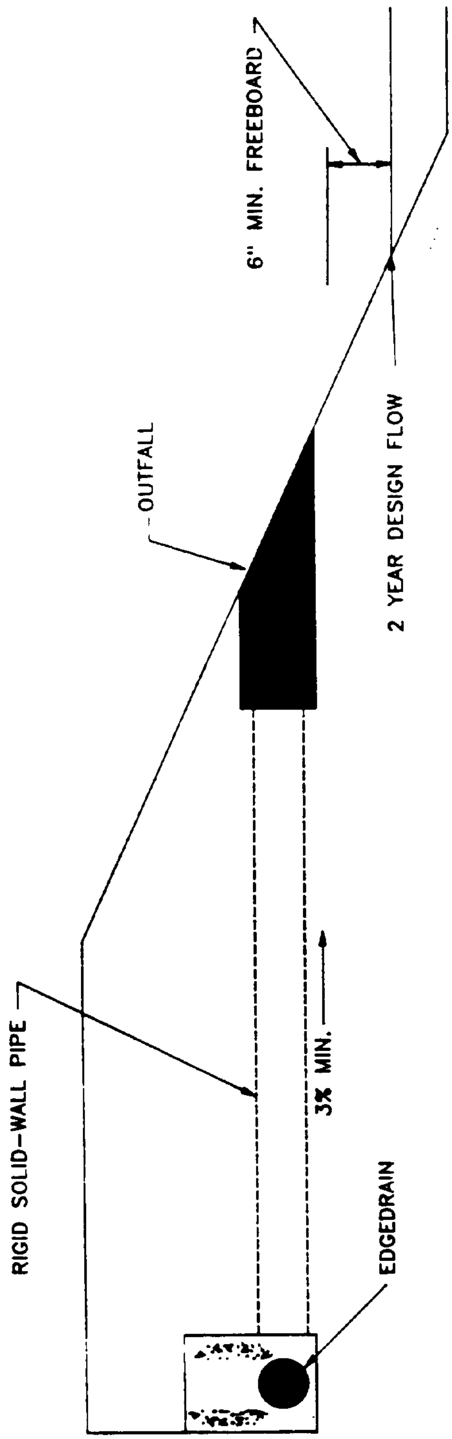


Figure 8. Outlet Pipe Design